## DEVELOPMENT OF SHROUDED TURBOJET TO FORM A TURBORAMJET FOR FUTURE MISSILE APPLICATIONS

**Suleiman M. al-Namani-Captain, Royal Army of Oman**
**B.Eng., Staffordshire University, 1992**
**Master of Science in Applied Physics-June 2000**
**Advisors: Garth V. Hobson, Department of Aeronautics and Astronautics**
**Karlheinz E. Woehler, Professor Emeritus**

Development of a shroud to form part of an afterburner for a turbo-ramjet engine which has a possible application for high speed long range missile applications. Research has been conducted on scram-jet engines with little or no emphasis on turbojet/ramjet combined cycle engines. With the possibility of the turbojet providing the thrust at subsonic conditions and the ramjet providing the thrust at supersonic conditions. A small turbojet engine, the Sophia J450, was evaluated experimentally and the results were compared to the prediction using an industry standard program with a perfect comparison over a wide operating range. In order to study possible turbo-ramjet configurations, a Sophia J450 turbojet engine was used with various shroud configurations, to compare static thrust and specific fuel consumption measured in a test rig. Shroud pressures were also recorded to determine the entrainment rate of the ducts. The short shroud results were found to produce the best performance of the three configurations tested. The performance improvements were more significant at lower engine spool speeds that produced a sharp increase in secondary entrainment pressure.

A conical supersonic intake was designed for combined cycle engine at a Mach 2 flight condition resulting in a near optimum cone angle of 15 (deg) to be tested in the new free jet facility. The flight envelope of the baseline engine was also determined over a wide range of flight speeds and operating altitudes.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Air Vehicles

**KEYWORDS:** Micro-Turbojet, GASTURB, Engine Shroud, Turboramjet, Sophia J450, Microturbine Performance

## PERFORMANCE AND SPACE BORNE APPLICATION ANALYSIS OF THE HIGHER ORDER CYCLOSTATIONARY BASED CLASSIFIER

**Brian K. Bailey-Captain, United States Air Force**
**B.S., Carnegie Mellon University, 1994**
**Master of Science in Astronautical Engineering-December 2000**
**Advisors: Brij N. Agrawal, Department of Aeronautics and Astronautics**
**Charles W. Therrien, Department of Electrical and Computer Engineering**
**Second Reader: Tri T. Ha, Department of Electrical and Computer Engineering**

Testing of the Higher Order Cyclostationary Based Classifier (HBC) is conducted to evaluate system operational performance. Utilizing Higher Order Cyclostationary (HOCS) analysis techniques, the HBC is designed to automatically detect and classify communication and radar signals contained in input signal samples. While test results utilizing earlier data were inconclusive on the effectiveness of the system, a more rigorous testing for Binary Phase-Shift Keying (BPSK) modulation scheme is herein carried out. The results of the HBC analysis reveal a system which experiences difficulty in performing modulation detection and classification of the input data at signal-to-noise ratios above 10 dB. The HBC automatic band-of-interest detector also shows evidence of interfering with accurate signal classification results. Recommended improvements to the algorithms and interface are presented to address these and other observed trends. An application of the HBC system to the Naval Research Laboratory's Pre-Configured Interface Payload (PCIP) program are assessed for space borne testing of the HBC system.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Computing and Software, Sensors, Modeling and Simulation

**KEYWORDS:** Cyclostationary, Digital Signals, Signal Classification, SignalIntelligence (SIGINT), Spacecraft Payload Integration, Pre-Configured Interface Payload (PCIP)

**ADAPTIVE MULTI-LAYER LMS CONTROLLER DESIGN AND ITS APPLICATION TO ACTIVE VIBRATION SUPPRESSION ON A SPACE TRUSS**

**Timothy A. Barney-Lieutenant, United States Navy**
**B.S., Eastern Michigan University, 1993**
**Master of Science in Mechanical Engineering-June 2001**
**Advisors: Young S. Shin, Department of Mechanical Engineering**
**Brij N. Agrawal, Department of Aeronautics and Astronautics**

This thesis develops an adaptive controller that actively suppresses a single frequency disturbance source at a remote position and tests the system on the NPS Space Truss. The experimental results are then compared to those predicted by an ANSYS finite element model. The NPS space truss is a 3.7-meter long truss that simulates a space-borne appendage with sensitive equipment mounted at its extremities. One of two installed piezoelectric actuators and an Adaptive Multi-Layer LMS control law were used to effectively eliminate an axial component of the vibrations induced by a linear proof mass actuator mounted at one end of the truss. Experimental and analytical results both demonstrate reductions to the level of system noise. Vibration reductions in excess of 50dB were obtained through experimentation and over 100dB using ANSYS, demonstrating the ability to model this system with a finite element model. This thesis also proposes a method to use distributed quartz accelerometers to evaluate the location, direction, and energy of impacts on the NPS space truss using the dSPACE data acquisition and processing system to capture the structural response and compare it to known reference signals.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Modeling and Simulation

**KEYWORDS:** Active Vibration Suppression, Piezoceramic Actuators, Impact Analysis, Adaptive Controller, LMS

**TIME DOMAIN VALIDATION OF THE SIKORSKY GENERAL HELICOPTER (GENHEL) FLIGHT DYNAMICS SIMULATION MODEL FOR THE UH-60L WIDE CHORD BLADE MODIFICATION**

**Robert L. Barrie, Jr.-Captain, United States Army**
**B.S., United States Military Academy, 1990**
**Master of Science in Aeronautical Engineering-December 1999**
**Advisors: E. Roberts Wood, Department of Aeronautics and Astronautics**
**Thomas H. Lawrence, Sikorsky Aircraft Corporation**

Helicopter design at the Sikorsky Aircraft Corporation is aided by the use of the Sikorsky General Helicopter (GenHel®) Flight Dynamics Simulation Model. Specifically, GenHel output is used by both handling qualities and maneuver loads engineers as a predictive design tool. Inherent in the use of an analytical model is the requirement for validation. This report seeks to validate the GenHel® flight dynamics simulation models used in the design of the UH-60L Wide Chord Blade (WCB) modification. Initially, comparisons are made between the current analytical models and flight test data for selected trim flight conditions and dynamic maneuvers. Based on the correlation of the data, modifications are made to the analytical model where necessary. The modified analytical model will be validated through a final comparison with test flight data. The goal of this report is to validate the use of Sikorsky's GenHel® flight simulation program as an analytic predictive tool in the design of the WCB modification and identify any areas where improvements could be applied. Validation of the WCB GenHel model serves two purposes. First it confirms the ability of GenHel to model the flight dynamic response of the UH-60L with the WCB

modification. Second it confirms the predictive loads forwarded to the structural engineers during the design phase of the WCB.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Modeling and Simulation

**KEYWORDS:** Helicopter Dynamics, Mathematical Modeling

### EXPERIMENTAL AND COMPUTATIONAL INVESTIGATION OF THE ENDWALL FLOW IN A CASCADE OF COMPRESOR BLADES

**James R. Carlson, II-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1991**
**Master of Science in Aeronautical Engineering-September 2000**
**Advisor: Garth V. Hobson, Department of Aeronautics and Astronautics**
**Second Reader: Raymond P. Shreeve, Department of Aeronautics and Astronautics**

An investigation of the three-dimensional flow in a cascade of second-generation controlled-diffusion blades, which was a result of the interaction of the endwall boundary layers with the blade profiles, is reported. Five-hole probe wake surveys were performed at various spanwise locations to determine the total pressure loss distribution. Downstream velocity vector information was also obtained from the five-hole probe surveys. Two-component laser-Doppler velocimetry (LDV) was used to characterize the flow in the inlet and wake regions. A numerical investigation of the flowfield was conducted using SWIFT, a computational fluid dynamics code developed by Dr. Roderick Chima of NASA Glenn Research Center. Experimental blade-surface pressure coefficients were compared with values predicted using SWIFT. Overall, good correlation between the five-hole probe and LDV measurement techniques was obtained; however, the CFD predictions did not match well with the experimental results, particularly at the midspan location of the blade where separation of the suction surface boundary layer occurred.

**DoD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power

**KEYWORDS:** Laser Doppler Velocimetry, Controlled-Diffusion Compressor Blading

### OPTIMIZATION PROCEDURE FOR ELECTRIC PROPULSION ENGINES

**John J. De Bellis-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1991**
**Master of Science in Applied Physics-December 1999**
**Advisors: Oscar Biblarz, Department of Aeronautics and Astronautics**
**James H. Luscombe, Department of Physics**

This thesis addresses the optimization of all types of space electrical propulsion thrusters. From the Langmuir-Irving payload mass fraction formulation, a "dual-optimum" solution is defined, yielding a minimum overall mass for a specified payload consistent with minimum transfer time. This solution fixes the ideal payload mass ratio ($m_{pl}$ / $m_o$) at a value of 0.45, establishing the ratios of effective exhaust velocity ($v$ / $v_c$) and incremental change of vehicle velocity ($\Delta u$ / $v_c$) to characteristic velocity at 0.820 and 0.327 respectively. The characteristic velocity ($v_c$) includes thrust time as well as engine efficiency ($\eta_t$) and specific power ($\alpha$). A range of mass ratios from 0.35 to 0.55 is used in order to allow the system designer some flexibility while remaining close to optimal. Nine examples are presented which demonstrate that mission profiles can be optimized by profile-to-thruster matching. A comprehensive list of currently available electric propulsion engines is provided. This list details important parameters such as the specific power, which "sizes" an engine in terms of power provided to the thruster at the cost of additional mass. Allowance is also made for a fuel tank mass penalty, and examples show that this can also noticeably influence the optimum design.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Space Vehicles

**KEYWORDS:** Space Propulsion, Electric Propulsion, Ion Engines, Hall Thrusters, Optimum Specific Impulse, Minimum Thrusting Time

### INCORPORATION OF ENHANCED GROUND PROXIMITY WARNING SYSTEM (EGPWS) IN THE NASA AMES RESEARCH CENTER CAE BOEING 747-400 FLIGHT SIMULATOR

**Robert A. DeGennaro-Commander, United States Navy**
**B.E., State University of New York Maritime College, 1984**
**Master of Science in Aeronautical Engineering-September 2000**
**Advisor: Russell W. Duren, Department of Aeronautics and Astronautics**
**Second Reader: Oleg A. Yakimenko, National Research Council Senior Research Associate**

The NASA Ames Research Center CAE Boeing 747-400 flight simulator is used primarily for the study of human factors in aviation safety. The simulator is constantly upgraded to maintain a configuration match to a specific United Airlines aircraft and maintains the highest level of FAA certification to ensure credibility to the results of research programs. United's 747-400 fleet, and hence the simulator, are transitioning from the older Ground Proximity Warning System (GPWS) to the state-of-the-art Enhanced Ground Proximity Warning System (EGPWS). GPWS was an early attempt to reduce or eliminate Controlled Flight Into Terrain (CFIT). Basic GPWS alerting modes include: excessive descent rate, excessive terrain closure rate, altitude loss after takeoff, unsafe terrain clearance, excessive deviation below glideslope, advisory callouts and windshear alerting. However, since GPWS uses the radar altimeter which looks straight down, ample warning is not always provided. EGPWS retains all of the basic functions of GPWS but adds the ability to "look ahead" by comparing the aircraft position to an internal database and provide additional alerting and display capabilities. This thesis evaluates three methods of incorporating EGPWS in the simulator and describes the implementation and architecture of the preferred option.

**DoD KEY TECHNOLOGY AREA:** Air Vehicles

**KEYWORDS:** Enhanced Ground Proximity Warning System, Ground Proximity Warning System, Controlled Flight Into Terrain, Terrain Alerting and Display, Terrain Clearance Floor, Flight Simulator, NASA

### COMPUTATIONAL FLUID DYNAMICS PREDICTION OF SUBSONIC AXIS-SYMMETRIC AND TWO-DIMENSIONAL HEATED FREE TURBULENT AIR JETS

**Michael D. DeWulf-Lieutenant, United States Navy**
**B.S., Iowa State University, 1993**
**Mechanical Engineer-September 2000**
**Master of Science in Mechanical Engineering-September 2000**
**Advisor: Knox T. Millsaps, Jr., Department of Mechanical Engineering**
**Second Readers: Garth V. Hobson, Department of Aeronautics and Astronautics**
**Arthur Shavit, Department of Mechanical Engineering**
**Terry R. McNelley, Department of Mechanical Engineering**

A study was conducted to evaluate the accuracy of a commercial computational fluid dynamics (CFD) code (CFDRC-ACE+) for predicting incompressible air jet flows with simple geometrics. Specifically, the axis-symmetric and two-dimensional heated air-jets were simulated using a standard $k$-$\varepsilon$ turbulence model. These CFD predictions were directly compared to an extensive compilation of experimental data from archive literature. The round jet results indicated that the code over-predicted the velocity-spreading rate by 24% and the temperature-spreading rate by 29%. In addition, the centerline velocity and temperature decay rates were also over-predicted, as well, by approximately 7.5 diameters for the velocity profiles and 10.5 diameters for the temperature profiles. The planar jet simulation was generally closer to experimental

data ranges, with an under-prediction of the velocity-spreading rate of approximately 17% with an over-predicated temperature spreading rate of 12%. The centerline velocity and temperature decay rates were both under-predicted at 22% and 27% respectively. Again, the geometric and kinematic virtual origins were over-predicted by approximately 7.5 slot heights for the velocity profiles and 10.5 slot heights for the temperature profiles.

**DoD KEY TECHNOLOGY AREA:** Modeling and Simulation

**KEYWORDS:** Computational Fluid Dynamics (CFD), Eductor, Ejector, Gas Turbine, Exhaust, Axisymmetric Jet, Two-Dimensional Jet, Air Jet, Free Turbulent, Jet

## AN EXPERIMENTAL INVESTIGATION OF FLAPPING WING PROPULSION FOR MICRO AIR VEHICLES

**Sean J. Duggan-Captain, Canadian Armed Forces**
**B.Eng., Royal Military College of Canada, 1995**
**Master of Science in Aeronautical Engineering-June 2000**
**Advisors: Kevin D. Jones, Department of Aeronautics and Astronautics**
**Max F. Platzer, Department of Aeronautics and Astronautics**

Flapping-wing propulsion is studied experimentally through thrust measurements and flow visualization. The objective of the research is to provide further insight into the aerodynamics of flapping-wing micro air vehicles (MAVs). Experimental work is conducted in the NPS 1.5 m x 1.5 m in-depth wind tunnel. A previously constructed model is suspended by thin wires and is used to measure the thrust performance of the flapping-wing MAV. For this experiment, the model is tested in four configurations; three with varying wing mount stiffness and the fourth with an articulated pitch mechanism. Thrust is indirectly determined using a laser range-finder to measure stream-wise deplacement of the model. Three methods of flow visualization are attempted to gain further insight into the flow-field around the MAV. First tufts are placed on and around the model to identify the flow-field. Second, a smoke rake placed outside the tunnel is used to route smoke into the test section. Thirdly, a smoke wire system is used to produce smoke in the test section. Experimental results are compared with flow visualization results and previous experimental and numerical work.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Other (Micro Air Vehicles)

**KEYWORDS:** Flapping Wing, Micro Air Vehicle, Low Reynolds Number, Flow Visibility

## TESTING AND DEVELOPMENT OF A SHROUDED GAS TURBINE ENGINE IN A FREEJET FACILITY

**Hector Garcia-Lieutenant Commander, United States Navy**
**B.S., University of California-Riverside, 1986**
**Master of Science in Applied Physics-December 2000**
**Advisors: Garth V. Hobson, Department of Aeronautics and Astronautics**
**Karlheinz E. Woehler, Professor Emeritus**

Testing and analysis of a shrouded turbojet engine with possible application for high speed propulsion on low cost Unmanned Combat Aerial Vehicles (UCAV), Unmanned Aerial Vehicles (UAV) and missiles was the subject of this thesis. The possibility of a turbojet providing thrust at subsonic conditions and the ramjet section providing the thrust in a supersonic regime exists. The combined cycle engine (CCE) could be incorporated into a variety of applications.

The building of new freejet facility and engine test rig at the Naval Postgraduate School enabled dynamic testing of the ongoing development of a turboramjet. The freejet facility and new engine stand performed without exception. The shrouded engine was dynamically tested in a freejet up to Mach 0.4.

The engine performance measurements closely matched those predicted by a cycle analysis program, GASTURB.

Computational fluid dynamics (CFD) was used to analyze the supersonic inlet at a design point of Mach 2. The results provided by the CFD code, OVERFLOW, matched theoretical flow parameters. The intake design was slightly modified to enhance performance of shock waves in the supersonic flight regime.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Air Vehicles

**KEYWORDS**: Micro-Turbojet, GASTURB, Engine Shroud, Turboramjet, Sophia J450, Microturbine

## VISION-BASED NAVIGATION FOR AUTONOMOUS LANDING OF UNMANNED AERIAL VEHICLES

**Paul A. Ghyze.-Lietenant Commander, United States Navy**
**B.S., United States Naval Academy, 1989**
**Aeronautical and Astronautical Engineering-September 2000**
**Advisors: Isaac I. Kaminer, Department of Aeronautics and Astronautics**
**Oleg A. Yakimenko, National Research Council Senior Research Associate**

The role of Unmanned Aerial Vehicles (UAVs) for modern military operations is expected to expand in the 21st Century, including increased deployment of UAVs from Navy ships at sea. Autonomous operation of UAVs from ships at sea requires the UAV to land on a moving ship using only passive sensors installed in the UAV to estimate the UAV position relative to the moving platform. A navigation algorithm based on photogrammetry and perspective estimation is presented for numerically determining the relative position and orientation of an aircraft with respect to a ship that possesses three visibly significant points with known separation distances. Original image processing algorithms that reliably locate visually significant features in monochrome images are developed. Monochrome video imagery collected during flight test with an infrared video camera mounted in the nose of a UAV during actual landing approaches is presented. The navigation and image processing algorithms are combined to reduce the flight test images into vehicle position estimates. These position estimates are compared to truth data to demonstrate the feasibility of passive, vision-based sensors for aircraft navigation. Conclusions are drawn, and recommendations for further study are presented.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Computing and Software, Sensors

**KEYWORDS:** Unmanned Aerial Vehicle, Navigation, Infrared Imaging, Image-Processing, MATLAB®, Simulation

## INVESTIGATION OF CROSS FLOW FAN PROPULSION FOR LIGHTWEIGHT VTOL AIRCRAFT

**Dean H. Gossett-Lieutenant Commander, United States Navy**
**B.S., Montana College of Mineral Science and Technology, 1984**
**Master of Science in Aeronautical Engineering-December 2000**
**Advisors: Max F. Platzer, Department of Aeronautics and Astronautics**
**Kevin D. Jones, Department of Aeronautics and Astronautics**

As world population increases, road and airport congestion will become increasingly prevalent. A small, cheap VTOL aircraft which can be flown from a driveway to the workplace parking lot would reduce traffic congestion and travel time. A lightweight, single seat commuter type VTOL aircraft is envisioned as the solution to this problem. To achieve a goal of minimum weight, the aircraft aerodynamic design should be optimized for forward flight. Vertical thrust augmentation from a propulsion unit contained within the fuselage would have little detriment to forward flight aerodynamics, and the cross flow fan can be accommodated as such. Cross flow fan propulsion has not been seriously considered for aircraft use since

an LTV Vought Systems Division study for the U.S. Navy in 1975. Despite an indepth knowledge of the design parameters and airflow relationships in cross flow fans, the existing data supports the hypothesis that with further development the thrust efficiency and thrust-to-weight ratio could improve to the point where this thrust producing method is viable. This study investigates the incorporation of rotary engine powered cross flow fan propulsion in a hypothetical lightweight VTOL aircraft and concludes that cross flow fan propulsion is viable but only with further investigation of power plant technology and fan design parameters and relationships.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Air Vehicles

**KEYWORDS:** VTOL, Cross Flow Fan, Ducted Propeller

**A NUMERICAL STUDY OF FUEL-OPTIMAL LOW-EARTH ORBIT MAINTENANCE**
**Lawrence E. Halbach-Major, United States Air Force**
**B.A.E.M., University of Minnesota, 1998**
**Master of Science in Astronautical Engineering-December 2000**
**Advisors: I.M. Ross, Department of Aeronautics and Astronautics**
**Fariba Fahroo, Department of Mathematics**

This thesis studies the fuel optimal periodic reboost profile required to maintain a spacecraft experiencing drag in low-earth-orbit (LEO). Recent advances in computational optimal control theory are employed, along with a Legendre-Gauss-Lobatto Pseudospectral collocation code developed at the Naval Postgraduate School, to solve the problem. Solutions obtained by this method are compared against a previous study. Key issues were checking the optimality of the solutions by way of the necessary conditions and the behavior of the solution to changes in the thruster size. The results confirmed Jensen's findings of propellant savings of one to five percent when compared against a middle altitude Force Keplerian Trajector (FKT). Larger savings are predicted if compared against a finite-burn Hohmann transfer with drag. The costates estimates compared favorable against necessary conditions of Pontryagin's Minimum Principle. Analysis of the switching function yielded period of thrust-modulated arcs. The optimal thrust profile appears to be a thrust-modulated burn to raise the orbit followed by an orbital decay and a terminating thrust-modulated arc. For a sufficiently low thrust-control authority, the switching structure includes a maximum thrust arc. Indirect optimization techniques to confirm these findings were unsuccessful.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles

**KEYWORDS:** Orbital Mechanics, Optimization, Optimal Control Theory, Orbit Maintenance

**TELEMETRY SYSTEMS ANALYSIS AND DESIGN**
**William K. Ham-Lieutenant, United States Navy**
**B.S., Texas Tech University, 1993**
**Master of Science in Astronautical Engineering-December 2000**
**Advisor: Brij Agrawal, Department of Aeronautics and Astronautics**
**Second Reader: Norm Sorensen, National Reconnaissance Office Chair Professor**

The Navy has a valuable opportunity to improve its own products and operations efficiency by showing its future leaders and designers how to design effective and viable telemetry, tracking, and commanding (TT&C) systems, and their operation. One system is the FLTSTAT military communications constellation of spacecraft, one of which has been a static display at the Naval Postgraduate School (NPS) until June, 2000. The primary objective was to make this spacecraft operational and thus provide a new operational spacecraft laboratory for other NPS students. This thesis may also be used as a primer for the space engineering or space operations student regarding TT&C system design. Great effort has been taken to

document and discuss current design practices and standards adopted by DoD laboratories, test facilities and operation centers. A TT&C system designed for a spacecraft incorporating all the traditional subsystems (payload, thermal, structural, power, TT&C, attitude control) is included.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Other (Communications)

**KEYWORDS:** Space Vehicles, Communications

### EXPLORATION OF FIBRE CHANNEL AS AN AVIONICS INTERCONNECT FOR THE 21ST CENTURY MILITARY AIRCRAFT

**Shawn P. Hendricks-Lieutenant Commander, United States Navy**
**B.S., United States Naval Academy, 1989**
**Aeronautical and Astronautical Engineer-September 2000**
**Master of Science in Aeronautical Engineering-September 2000**
**Advisor: Russell W. Duren, Department of Aeronautics and Astronautics**
**Second Reader: John C. McEachen, Department of Electrical and Computer Engineering**

Avionics architecturers are evolving from "Federated" systems consisting of highly specialized black boxes connected together via MIL-STD-1553 and ARINC 429 data buses to "Integrate" and "Distributed" architectures. These new architecturers contain high data-rate sensors, parallel processors, and shared memory with high levels of integration. These systems require a new interconnection system that overcomes the limitations of older standards. One such interconnection system is Fibre Channel. This thesis evaluates Fibre Channel as avionics interconnection standard. It begins by defining the requirements and measures of performance for an interconnection system suitable for the new avionics architectures. The requirements address technical performance, affordability, reliability, sustainability, and maintainability considerations. The Fibre Channel standards are then compared to the requirements for the avionics interconnection system. In order to perform a technical performance evaluation of a switched fabric avionics interconnection system, a computer simulation model was developed. The OPNET Modeler® tool from OPNET, Inc. was used to model the components of an advanced avionics system. The results of this simulation demonstrated that Fibre Channel meets all the performance requirements of an avionics interconnect.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Computing and Software, Electronics, Modeling and Simulation

**KEYWORDS:** Fibre Channel, Interconnect, Avionics, Bandwidth, Modeling, Simulation

### PROPAGATION OF A TWO-PHASE DETONATION ACROSS A GEOMETRIC DIFFRACTION WITH COMPOSITIONAL DISCONTINUITY

**Todd A. Hofstedt-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1993**
**Aeronautical and Astronautical Engineer-June 2000**
**Advisors: Christopher M. Brophy, Department of Aeronautics and Astronautics**
**David W. Netzer, Department of Aeronautics and Astronautics**
**Raymond P. Shreeve, Department of Aeronautics and Astronautics**

The research program involved the modification and use of an existing pulse detonation engine (PDE) to investigate the detonability of a JP-10/air aerosol. The detonation of a JP-10 aerosol in air proved more difficult than was originally anticipated.

The use of a small JP-10/oxygen pre-detonator to provide direct initiation results in a transition region with a geometric diffraction and compositional discontinuity. Propagation of a detonation into such a region is very complex but critical to the re-establishment of the detonation wave in the JP-10/air mixture.

A high-speed camera was used to image the wave in the transition region and provide spatial information. High frequency pressure transducers were used along the combustor axis to determine wave speed. The ultimate goal was to determine the conditions required to ensure reliable re-establishment of a detonation wave in the JP-10/air aerosol mixture.

Unfortunately, the confined planar JP-10/oxygen detonations in the pre-detonator were unable to transition into unconfined spherical detonation fronts in the JP-10/air aerosol. Furthermore, the ratio of main combustor diameter to pre-detonator diameter was too large to allow re-initiation of detonation at the main combustor wall.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** JP-10, Detonations, Pulse Detonation Engines, Tactical Missile Propulsion

### SYSTEM ENGINEERING ASPECTS OF VTOL ROTORCRAFT: AN EXTENSION OF THE SIKORSKY ASSET CONCEPT DESIGN TRADE STUDY FOR THE UNITED STATES COAST GUARD DEEPWATER PROGRAM

**Heath M. Howell-Lieutenant, United States Navy**
**B.S., University of Florida, 1991**
**Master of Science in Aeronautical Engineering-March 2000**
**Advisor: Conrad F. Newberry, Department of Aeronautics and Astronautics**
**Second Reader: Lynn M. Tinker, Sikorsky Aircraft Corporation**

This thesis develops and uses systems engineering methods for the selection of vertical takeoff and landing (VTOL) rotorcraft for a specified mission. It proposes a general process for performing design trade studies as they apply to the selection of the Medium Range Rotorcraft (MRR) and Ship Based Unmanned Air Vehicle (SUAV) assets that are best suited in fulfilling the United States Coast Guard's Integrated Deepwater System (IDS) Concept of Operation (CONOPS). This thesis defines the phases that encompass a comprehensive trade-off analysis process. This thesis also describes an example of this process as used in the MRR and SUAV asset selection for the Sikorsky Deepwater Phase IA proposal. A method of validating the affordability criteria of the trade study through a derived life cycle cost (LCC) cost estimating relationship (CER) is formulated through the use of multiple variable regression analysis. A method of validating the flight performance criteria of the trade study is proposed using mission profile modeling and simulation (M&S). The Taguchi Method is used to analyze parameter sensitivity effects in the LCC model, and a selection criteria weight factor sensitivity analysis is conducted on the Trade Study Element Matrix.

**DoD KEY TECHNOLOGY AREA:** Air Vehicles

**KEYWORDS:** Trade-off Analysis Process, Deepwater, Cost Estimating Relationship (CER)

### UNMANNED AERIAL VEHICLES AND SPECIAL OPERATIONS: FUTURE DIRECTIONS

**Gregory K. James-Major, United States Army**
**B.S., University of Washington, 1998**
**Master of Science in Defense Analysis-December 2000**
**Advisor: Gordon H. McCormick, Special Operations Academic Group**
**Second Reader: E. Roberts Wood, Department of Aeronautics and Astronautics**

Advances in computing, miniaturization, imaging, and data transmission technologies are precursors to a more important role for UAVs in warfare. UAVs are likely, first, to revolutionize the way reconnaissance and surveillance are conducted, second to increase the capabilities of small units, third to join manned platforms in the conduct of assault and attack missions, and finally help provide the numerous nodes necessary to facilitate both the digital connectivity and swarming forces envisioned in future networkcentric formations.

This thesis focuses on answering six questions:

-What missions can UAVs perform?
-What missions should UAVs perform?
-What type of UAV is appropriate for each mission?
-How can SOF use UAVs?
-Who should own the UAV (from a SOF perspective)?
-What level of control is required and where?

Results include what UAV missions and types could support special operations, which of these should be performed by UAVs organic to special operations, and which should be performed by the Services' UAVs, as well as recommendations for future command and control of UAVs supporting special operations. Results are presented in matrix form for easy correlation of related factors. The thesis concludes with a twenty-year prognostication of UAV development and recommends areas for future study.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Battlespace Environments, Command and Control and Communications, Electronic Warfare, Sensors

**KEYWORDS:** Unmanned Aerial Vehicles, UAV, Special Operations Forces, SOF, Future of Warfare

**A PROJECTILE FOR A RECTANGULAR BARRELED RAIL GUN**

**Francisco M. Juanche-Lieutenant Commander, United States Navy**
**B.A., San Francisco State University, 1987**
**Master of Science in Applied Physics-December 1999**
**Advisors: Conrad F. Newberry, Department of Aeronautics and Astronautics**
**William B. Maier, II, Department of Physics**

The Physics Department at the Naval Postgraduate School is developing a concept to overcome the problems that keep present rail guns from being practical weapons. The rails must be replaced often if the rail gun operation is to be continuous. Replacing the rails in present rail gun configurations is time consuming. The Physics Department's design concept uses a rectangular barrel as part of the solution to the problem of replacing the rails. The projectile will require flat surfaces to maintain electrical contact with the flat rails and aerodynamic stabilization because of the lack of angular momentum. This thesis develops one possible model of a projectile for a rectangular barreled rail gun, which could be used to replace the standard five-inch gun found on most warships. The proposed projectile is successfully modeled as a five inch projectile with flat areas planed onto opposite sides and long chord, short span fins attached in a cruciform configuration. The computer programs used to develop the projectile model are included to allow evaluation of alternate configurations.

**DOD KEY TECHNOLOGY AREAS:** Conventional Weapons, Modeling and Simulation

**KEYWORDS:** Projectiles, Rail Guns, Computer Modeling

## DESIGN, CHARACTERIZATION, AND PERFORMANCE OF A VALVELESS PULSE DETONATION ENGINE

**Robert G. Johnson-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1992**
**Master of Science in Astronautical Engineering-June 2000**
**Advisor: Christopher H. Brophy, Department of Aeronautics and Astronautics**
**Second Reader: David W. Netzer, Department of Aeronautics and Astronautics**

Current interest in developing a low cost, less complex tactical missile propulsion system that operates on readily available liquid fuels and can operate from low subsonic to a flight Mach number of 5 is driving research on pulse detonation engines.

This research program involved the design, construction, and testing of a valveless Pulse Detonation Engine using a JP-10/air mixture as the primary combustible reactants. A small JP-10/oxygen pre-detonation tube was used to initiate the detonation in the JP-10/air mixture in the engine. The engine was tested at various inlet conditions and equivalence ratios in order to determine the detonable regime of the fuel/air mixture. The original area transition from the pre-detonation tube to the main combustion tube appeared to be too extreme, so a tube was added to extend the pre-detonation tube into the throat of a shock focusing device inserted flush with the head end of the main combustion tube to promote more favorable transition conditions.

In addition, the effects of a transient detonation process on the inlet operation and performance of the engine was theoretically predicted, using a two dimensional grid in a viscous computational fluid dynamics code, and experimentally evaluated from subsonic to supersonic operation.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** Pulse Detonation Engine, JP-10, Liquid Fuels, Combustion

## UH-60 BLACK HAWK DISTURBANCE REJECTION STUDY FOR HOVER/LOW SPEED HANDLING QUALITIES CRITERIA AND TURBULENCE MODELING

**Steven J. Labows-Lieutenant Commander, United States Navy**
**B.S., Cornell University, 1988**
**Master of Science in Aeronautical Engineering-March 2000**
**Advisors: Mark B. Tischler, Army/NASA Rotorcraft Division, NASA Ames Research Center**
**E. Roberts Wood, Department of Aeronautics and Astronautics**
**Second Reader: Chris L. Blanken, Army/NASA Rotorcraft Division, NASA Ames Research Center**

Helicopters operate in an environment where task performance can easily be affected by atmospheric turbulence. This paper discusses the airborne flight test of the Sikorsky UH-60 Black Hawk helicopter in turbulent conditions to determine disturbance rejection criteria and to develop a low speed turbulence model for helicopter simulation. A simple approach to modeling the aircraft response to turbulence is described by using an identified model of the Black Hawk to extract representative control inputs that replicate the aircraft response to disturbances. This parametric turbulence model is designed to be scaled for varying levels of turbulence and utilized in ground or in-flight simulation. Flight control cutoff frequency data are also analyzed to support design criteria for gust rejection handling qualities.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Modeling and Simulation

**KEYWORDS:** Low Speed Helicopter Handling Qualities, Turbulence Modeling, Cutoff Frequency, Flight Control Design Requirements

## DARK CURRENT ANALYSIS AND COMPUTER SIMULATION OF TRIPLE-JUNCTION SOLAR CELLS

**Brendan P. Lewis-Captain, United States Air Force**
**B.S., United States Air Force Academy, 1989**
**Master of Science in Astronautical Engineering-December 1999**
**Master of Science in Electrical Engineering-December 1999**
**Advisors: Sherif Michael, Department of Electrical and Computer Engineering**
**Oscar Biblarz, Department of Aeronautics and Astronautics**
**Second Reader: Todd Weatherford, Department of Electrical and Computer Engineering**

This thesis reports the steps taken to characterize the semiconductor properties of triple-junction solar cells. Chemically etching the solar cells exposes each of the three energy producing junctions, InGaP, GaAs and Ge, to probes. Dark current measurements reveal the diode ideality factors of each junction, and these results are compared to current theories on diodes and solar cells. Calculations performed on experimentally obtained values from previous studies and measured values from this research for individual junctions show an expected diode ideality factor for the entire solar cell of 6.2 to 6.4, which is close to the actual production cell value of 5.9. Silvaco International's semiconductor simulation software was used to model the solar cell under dark and illuminated conditions. The simulated dark current yields an ideality factor of 3.45—lower than expected. A spectral analysis equating wavelength of light to current production for each junction within the solar cell is presented, and methods to better match the current produced from each junction are investigated. A current-versus-voltage-curve comparison equates simulated results to actual manufactured cell performance under illumination conditions; simulated values were within 10% for $V_{OC}$ and 15% for $I_{SS}$ in the better performing junctions.

**DoD KEY TECHNOLOGY AREA:** Space Vehicles

**KEYWORDS:** Solar Cell, Multijunction, Tunneling, Software Simulation, Dark Current, GaAs, InGaP, GaInP, Ge

## A COMPUTATIONAL AND EXPERIMENTAL INVESTIGATION OF FLAPPING WING PROPULSION

**Timothy C. Lund-Lieutenant, United States Navy**
**B.S., University of Arizona, 1990**
**Master of Science in Aeronautical Engineering-March 2000**
**Advisors: Kevin D. Jones, Department of Aeronautics and Astronautics**
**Max F. Platzer, Department of Aeronautics and Astronautics**

Flapping-wing propulsion is studied experimentally and numerically. The objective of the research is to provide further insight into the aerodynamics of flapping-wing air vehicles. Experimental work is conducted in the NPS 1.5 m x 1.5 m (5 ft x 5 ft) in-draft wind tunnel. A previously constructed long-span flapping-wing model suspended by cables is used to approximate the two-dimensional nature of the numerical simulation. For this experiment, the model is configured with two wings executing plunge-only motion. Thrust is indirectly determined by using a laser rangefinder to measure streamwise displacement of the model. Results are compared with previous experimental tests. A numerical analysis is conducted using USPOT, a locally developed unsteady panel code that models two independently moving airfoils with three degrees of freedom and non-linear deforming wakes. Thrust and efficiencies are computed for harmonically oscillating airfoils. Direct comparison is made between experimental and numerical thrust measurements.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Air Vehicles

**KEYWORDS:** Flapping Wing, Low Reynolds Number, USPOT, Panel Code, Laser Doppler Velocimetry, LDV

**EVALUATION OF THE USE OF CPS-AIDED WEAPONS TO ATTACK MOVING TARGETS**

**Randolph L. Mahr-Commander, United States Navy**
**B.S., United States Naval Academy, 1983**
**Master of Science in Aeronautical Engineering-March 2001**
**Advisor: Russell W. Duren, Department of Aeronautics and Astronautics**
**Second Reader: Morris R. Driels, Department of Mechanical Engineering**

The current intelligence gathering and strike decision infrastructure is optimized to handle geographically and temporally fixed targets. When tasked to respond to targets that require near immediate engagement, however, the system is stressed to the limit of its capability. When these time sensitive targets are capable of relocating, the process of rapidly applying lethal force becomes even more complicated. This thesis examines the problems associated with attacking a moving target using low cost GPS-aided standoff weapons, without an integrated weapon seeker. It begins with a discussion of the history and evolution of the Navy's ability to attack time sensitive moving targets, and provides the description of a system that could address shortcomings noted. MATLAB® Simulink® was used to develop a model to simulate the proposed system, and determine the responses to various combinations of identified error sources. The results of the research showed that the type of system proposed is technically feasible.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Command, Control and Communications, Conventional Weapons, Sensors, Modeling and Simulation, Time Critical Strike, Other (Time Critical Strike)

**KEYWORDS:** GPS, Weapons, Modeling, CEP, Time Sensitive Targets, Command, Control and Communications, Conventional Weapons, Sensors, Modeling and Simulation, Time Critical Strike, Stand-off Weapons

**CALIBRATION TO DETERMINE PRESSURE AND TEMPERATURE SENSITIVITIES OF A PRESSURE-SENSITIVE PAINT**

**Judith A. Muller-Ensign, United States Navy**
**B.S., Rensselaer Polytechnic Institute, 1999**
**Master of Science in Aeronautical Engineering-June 2000**
**Advisor: Raymond P. Shreeve, Department of Aeronautics and Astronautics**
**Second Reader: Garth V. Hobson, Department of Aeronautics and Astronautics**

In order to obtain quantitative surface pressure measurements of a transonic compressor rotor using pressure sensitive paint (PSP), the temperature dependence of the paint must be taken into consideration. In the present study, a calibration chamber was built and instrumented such that pressure and temperature could be controlled independently. Photodiodes were used to measure the intensity of light emitted by the PSP. An acquisition program was developed to record the necessary calibration data to obtain an analytical representation of the luminescent response of the pressure-sensitive paint over a range of pressures and temperatures characteristic of transonic fans.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** Pressure-Sensitive Paint, Photoluminescence, Luminescence, PtOEP, UV Illumination, Detection, Emission, Aerodynamics, Measurements, Temperature and Pressure Calibration

**EA-6B FOLLOW-ON STUDY: UAVS AND UCAVS**
**Lawrence Nance-Ensign, United States Navy**
**B.S., United States Naval Academy, 1999**
**Master of Science in Aeronautical Engineering-June 2000**
**Advisor: Russell W. Duren, Department of Aeronautics and Astronautics**
**Second Reader: Phillip E. Pace, Department of Electrical and Computer Engineering**

The DoD's only air-based EA jamming capability is provided by 123 EA-6B Prowlers. It is projected that these 123 aircraft will no longer adequately support required Airborne Electronic Attack (AEA) missions beyond the year 2010 due to attrition and airframe life limits. In order to maintain the tactical advantage over enemy air defenses, the DoD must augment and ultimately replace its aging and diminishing fleet of EA-6B aircraft with an equal or better AEA capability. Integrated Product Teams (IPT) are conducting an Analysis of Alternatives (AOA) to define operational requirements that address the DoD's AEA needs. The principal contribution of this thesis is to identify those unmanned aerial vehicles (UAVs) and unmanned combat aerial vehicles (UCAVs) that can be utilized in the future for AEA. UAV Electronic Warfare (EW) payloads and smart weapons that could help in this area are presented as well. While much has already been written concerning UAVs, few resources exist that discuss the feasibility of UAV programs in the realm of EW. Even fewer resources discuss how these unmanned platforms must be linked in the future to conduct network-centric warfare. This thesis attempts to bridge that gap.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Electronic Warfare, Other (Airborne Electronic Attack)

**KEYWORDS:** Airborne Electronic Attack, EA-6B, Electronic Attack, Electronic Warfare, Jamming, Network Centric Warfare, Payloads, Precision Guided Weapons, Smart Weapons, UAV, UCAV

**TRANSONIC COMPRESSOR TEST RIG REBUILD AND INITIAL RESULTS WITH THE SANGER STAGE**
**Joseph M. O'Brien-Ensign, United States Navy**
**B.S., United States Naval Academy, 1999**
**Master of Science in Aeronautical Engineering-June 2000**
**Advisor: Raymond P. Shreeve, Department of Aeronautics and Astronautics**
**Second Reader: Garth V. Hobson, Department of Aeronautics and Astronautics**

The NPS Transonic Compressor Test Rig was rebuilt and initial testing was conducted on the Sanger Stage, which was designed using CFD techniques. Improvements to the existing monitoring equipment, test rig instrumentation, and data acquisition software were all made in preparation for testing. A Plexiglas casewall was chosen to accommodate pressure-sensitive paint measurements. Wall heating was used to control tip-clearance. The initial performance data, to 70% design speed, were compared with predictions using a 3-dimensional viscous code.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** Compressor, Transonic, CFD, Turbomachinery, Tip Clearance

**IMPLEMENTATION OF A TWO PROBE TIP-TIMING TECHNIQUE TO DETERMINE COMPRESSOR BLADE VIBRATIONS**

**Nicholas G. Osburn-Ensign, United States Navy**
**B.S., United States Naval Academy, 1999**
**Master of Science in Aeronautical Engineering-June 2000**
**Advisor: Raymond P. Shreeve, Department of Aeronautics and Astronautics**
**Second Reader: Garth V. Hobson, Department of Aeronautics and Astronautics**

This study involved the implementation and validation of a blade-tip time of arrival (TOA) measurement technique, and the development of a computer program to analyze TOA data using a recently published approach. The program was used to analyze experimental compressor data taken in-house using two laser light probes, data generated computationally, and data obtained by others in a compressor test. The in-house compressor data was compared successfully to amplitudes obtained by strobed digital photography. A resonance was successfully detected in the supplied compressor data set.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** Tip-timing, Non-Contact Measurement, Blade Vibration

**ANGULAR RATE ESTIMATION FOR MULTI-BODY SPACECRAFT ATTITUDE CONTROL**

**William J. Palermo-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1992**
**Master of Science in Astronautical Engineering-June 2001**
**Aeronautical and Astronautical Engineer-June 2001**
**Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics**
**Second Reader: Harold A. Titus, Department of Electrical and Computer Engineering**

Spacecraft with high performance attitude control systems requirements have traditionally relied on imperfect mechanical gyroscopes for primary attitude determination. Gyro bias errors are connected with a Kalman filter algorithm that uses updates from precise attitude sensors like star trackers. Gyroscopes, however, have a tendency to degrade or fail on orbit, becoming a life-limiting factor for many satellites. When Errors become erratic, pointing accuracy may be lost during short star gaps. Unpredictable gyros degradations have impacted NASA spacecraft missions such as Skylab and Hubble Space Telescope as several DoD and ESA satellites. An alternative source of angular rate information is a software implemented real tie dynamic model. Inputs to the model from internal sensors and known spacecraft parameters enable the tracking of total systemangular momentum from which body rates can be determined. With this technique, the Kalman filter algorithm provides error corrections to the dynamic model. The accuracy of internal sensor and input parameters determine the effectiveness of this angular rate estimation technique. This thesis presents the background for understanding and implementation of the technique into a representative attitude determination system. The system is incorporated into an attitude simulation model developed in SIMULINK to evaluate the effects of dynamic modeling errors and sensor inaccuracies. Results are presented that indicate that real time dynamic modeling is an effective method of angular rate determination for maneuvering multi-body spacecraft attitude control systems.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Modeling and Simulation

**KEYWORDS:** Dynamic Gyro, Kalman Filter, Attitude Determination, Rate Estimation, Star Trackers, Attitude Simulation, Multi-body Dynamics, MATLAB, SIMULINK

**SPACECRAFT INTEGRATED DESIGN TOOLS**
**Troy W. Pannebecker-Major, United States Air Force**
**B.S., Pennsylvania State University, 1987**
**Master of Science in Astronautical Engineering-December 1999**
**Aeronautical and Astronautical Engineer-December 1999**
**Advisors: Brij N. Agrawal, Department of Aeronautics and Astronautics**
**Herschel H. Loomis, Jr., Department of Electrical and Computer Engineering**

The thesis surveys current software tools to design satellites and develops an integrated spreadsheet-based tool for preliminary spacecraft design. First, several existing and future design tools - both commercially available and company proprietary - are discussed and evaluated. Second, a spreadsheet-based design tool which is generally applicable to any earth-orbiting satellite is developed. Preliminary design of all satellite subsystems is performed on separate sheets of the Excel workbook. Based on user-entered orbital data propellant and mass budgets are also calculated. The design technique and spreadsheet implementation is presented along with the underlying "first principles" theory and equations.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Computing and Software

**KEYWORDS:** Spacecraft, Satellites, Design Tools, Concurrent Engineering

**ACTIVE VIBRATION CONTROL METHOD FOR SPACE TRUSS USING PIEZOELECTRIC ACTUATORS AND FINITE ELEMENTS**
**Carey M. Pantling-Lieutenant, United States Navy**
**B.S.A.E., University of Florida, 1993**
**Master of Science in Mechanical Engineering-December 1999**
**Master of Science in Astronautical Engineering-December 1999**
**Advisors: Young S. Shin, Department of Mechanical Engineering**
**Brij N. Agrawal, Department of Aeronautics and Astronautics**

This thesis created an analytical model for active vibration control of the NPS space truss using ANSYS. The NPS space truss is a 3.7-meter long truss that simulates a space-borne appendage with sensitive equipment at its extremities. With the use of a dSPACE data acquisition and processing system, quartz force transducer and piezoelectric actuator, active controls using an integral plus double integral control law were used to damp out the vibrations caused by a linear proof mass actuator. Vibration reductions on the order of 15-20 dB were obtained with experiment.

The ANSYS finite element model used SOLID5 elements to model the piezoelectric characteristics and ANSYS Parametric Design Language to provide for an iterative approach to an active controls analysis. Comparative data runs were performed with the ANSYS model to determine its similarity to experiment. The analytical model produced power reductions of 18-22 dB, demonstrating the ability to model the control authority with a finite element model. This technique can be used and modified to enhance its flexibility to many types of controls and vibration reduction applications. An analytical model for active control of the NPS space truss using MATLAB/Simulink was also developed as an alternative to the ANSYS model.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Materials, Processes and Structures, Modeling and Simulation

**KEYWORDS:** Active Vibration Control, Piezoceramic Actuators, ANSYS, Finite Element Method

## THE NPS SPACECRAFT COST MODEL: TAILORING CURRENT COMMERCIAL SPACECRAFT COST MODELS FOR NAVAL POSTGRADUATE SCHOOL SATELLITE PROGRAMS

**Michael D. Rayfield-Lieutenant Commander, United States Navy**
**B.S., University of South Carolina, 1986**
**Master of Science in Astronautical Engineering-December-1999**
**Advisors: Brij N. Agrawal, Department of Aeronautics and Astronautics**
**Alfred N. Sorensen, National Reconnaissance Office Chair Professor**

The successful launch of the Naval Postgraduate School (NPS) Petite Amateur Navy Satellite (PANSAT) led to the development of a follow-on satellite program at NPS. Until now, there did not exist a NPS specific cost modeling procedure to ensure accurate pricing information for program management. From the Preliminary Design Review of NPSat an initial attempt at modeling this program was conducted by the author. This thesis will provide an evaluation of this initial model and address procedures for refining the initial estimate with the purpose of providing a generic NPS Cost Model. This model will tailor current commercial cost model outputs to provide accurate price estimates for NPS specific programs. The commercial cost models used were Science Applications International Corporation's (SAIC) NAFCOM model and Aerospace's Small Satellite Cost Model (SSCM). These models do not take into account a university atmosphere where staffs and facilities are reduced. A method of tailoring the outputs of these programs was conducted and integrated into an Excel based spreadsheet. The resultant product is the Naval Postgraduate School's first Cost Modeling program which allows NPS satellite program management to input results from the SSCM and NAFCOM models and output expected cost data.

**DoD KEY TECHNOLOGY AREA:** Space Vehicles

**KEYWORDS:** Spacecraft Cost Modeling, Parametric Estimation, Satellite Design

## TARGETING AND FIRE CONTROL SYSTEM ANALYSIS OF THE NEW TURKISH ATTACK HELICOPTER "THE AH-IZ KINGCOBRA"

**Gokhan Lutfu Reyhand-First Lieutenant, Turkish Army**
**Master of Science in Aeronautical Engineering-March 2001**
**Advisors: Russell W. Duren, Department of Aeronautics and Astronautics**
**Alfred W. Cooper, Department of Physics**

In May of 1997, the Turkish Military issued a Request for a Proposal for the purchase of 145 attack helicopters. Turkey has chosen Bell Helicopter's KingCobra as its attack helicopter. The major difference between the USMC version of the AH-IZ and the Turkish version KingCobra is the Targeting and Fire Control System. Bell helicopter Textron has chosen Lockheed Martin to develop and build a new targeting system, the Target Sight System (TSS). The TSS will contain Lockheed Martin's 3-5μm midwave staring array FLIR. On the other hand, the Turkish Secretariat for Defense Industries (SSM) has chosen Aselsan ASELFLIR-300T that contains an 8-12μm longwave scanning second-generation FLIR.

A comparison of range performance for these two systems has been made using the TAWS Field Performance Model. Since the physical parameters on these specific FLIRs are proprietary, the FLIR92 Simulation Model is used to generate performance parameters. These parameters are expected to represent the general characteristics of the two systems. The resultant data is used in the TAWS Field Performance Model to predict the range performances.

The results have shown that the staring array midwave FLIR has longer ranges in the scenarios given in this thesis. This may not represent the real performance of the systems.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Sensors, Other (Thermal Imaging Systems)

**KEYWORDS:** Thermal Imaging Systems, Targeting, Fire Control Systems, Forward Looking Infrared, FLIR, TAWS, KingCobra, Attack Helicopter, Infrared

## INFLUENCE OF IGNITION ENERGY, IGNITION LOCATION, AND STOICHIOMETRY ON THE DEFLAGRATION-TO-DETONATION DISTANCE IN A PULSE DETONATION ENGINE

**John P. Robinson, III-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1993**
**Master of Science in Applied Physics-June 2000**
**Advisors: Christopher M. Brophy, Department of Aeronautics and Astronautics**
**Thomas J. Hofler, Department of Physics**

The feasibility of utilizing detonations for air-breathing propulsion is the subject of a significant research effort headed by the Office of Naval Research. Pulse Detonation Engines (PDE) have a theoretically greater efficiency than current combustion cycles. However, pulse detonation technology must mature beginning with research in the fundamental process of developing a detonation wave. This thesis explores various ignition conditions which minimize the deflagration-to-detonation transition distance ($X_{DDT}$) of a single detonation wave in a gaseous mixture.

Specifically, the minimum $X_{DDT}$ was determined for different Ethylene and Oxygen/Nitrogen gaseous mixtures under varying ignition energy (0.33-8.31 Joules), mixture equivalence ratios (0.6-2.0), and ignitor locations. To conduct the experiments a 6 feet long, 3 inch diameter tube combustor, support equipment, and operating software was built. Four independent test scenarios were investigated and trends developed to determine the minimum $X_{DDT}$ while reducing oxidizer blend ratios.

Results show that $X_{DDT}$ significantly depends on mixture equivalence ratio ($\varphi$) and was minimized at $\varphi \approx 1.1$. No dependence on ignition energies greater than 0.5 Joules was observed. A further reduction in $X_{DDT}$ was observed with the ignitor located one combustor diameter from the head wall. These results will be useful in future designs of pre-detonators for larger PDEs.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** Detonation, Pulse Detonation Engine, Deflagration-to-Detonation Transition, DDT

## PROTOTYPE DESIGN OF NPSAT VISIBLE IMAGER

**Michael J. Robison-Lieutenant, United States Navy**
**B.S., University of Washington, 1993**
**Master of Science in Astronautical Engineering-June 2000**
**Advisor: Richard C. Olsen, Department of Physics**
**Second Reader: Brij N. Agrawal, Department of Astronautical Engineering**

The objective of this work was to design and construct a prototype imager for the NPS remote sensing satellite. This project is a low-earth orbiting satellite designed to image the earth in VNIR and LWIR at a resolution of 100–200 m.

The specific imager design considered here is the VNIR instrument, designed to image the daylit earth and atmosphere, as well as the relatively dim aurora (northern lights) at multiple discrete wavelengths. This project defined the desired wavelengths to be: 427.8 nm, 470.9 nm, 557.7 nm, 630.0 nm, 636.4 nm, and 844.6 nm.

A Kodak 763 X 512 CCD was implemented into a push-broom scanner design appropriate for our mission. Design optics are for a nominal F/2, 90 mm Leica lens. The prototype was completed and demonstrated to operate.

**DOD KEY TECHNOLOGY AREAS:** Sensors, Electronics

**KEYWORDS:** Satellite, Imager, Aurora, Optics

## FEASIBILITY OF TWO-GIMBAL PLATFORM TUMBLING TO MINIMIZE VELOCITY ERROR (U)

**Bryan T. Schlotman-Lieutenant, United States Navy**
**B.S., Virginia Commonwealth University, 1993**
**Master of Science in Astronautical Engineering-June 2000**
**Advisor: I. Michael Ross, Department of Aeronautics and Astronautics**
**Second Readers: Peter Howard, Charles Stark Draper Laboratory**
**Andrew Staugler, Charles Stark Draper Laboratory**

Abstract is classified.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Space Vehicles, Surface/Under Surface Vehicles - Ships and Watercraft

**KEYWORDS:** Gimbal Tumbling, Trajectory Optimization

## MEASUREMENT OF FUEL ADDITIVE EFFECTS ON THE SOOT MASS LOADING IN OXYGEN/KEROSENE EXHAUST PLUMES

**Zachary M. Scruton-Lieutenant Commander, United States Navy**
**B.S., United States Naval Academy, 1988**
**M.S., Georgia Institute of Technology, 1995**
**Master of Science in Applied Physics-June 2000**
**Advisors: Christopher M. Brophy, Department of Aeronautics and Astronautics**
**David W. Netzer, Department of Aeronautics and Astronautics**
**D. Scott Davis, Department of Physics**

Measurements of the soot mass loading in the exhaust of a small liquid rocket engine burning gaseous oxygen with kerosene and kerosene with additive mixtures have been made. The rocket engine was operated over a high soot-producing regime, to simulate the film-cooling region of an actual system, which covered an oxygen-to-fuel ratio (O/F) range of 0.6 to 1.3 and produced a nearly uniform plume distribution. Using a dual fuel tank system, the fuel source was switched during the runs to allow both kerosene and kerosene with additive measurements to be conducted during the same run to ensure nearly identical engine operating conditions. A multi-wavelength optical transmission technique was used to determine the amount of soot present and utilized the transmission ratio of six wavelengths from the near UV to the visible through the plume of the engine. The experimental technique was analyzed to determine the potential error introduced when the transmission values were extremely low (<5%) and what potential effect any organic absorbers (PAHs) may have had on the transmission ratios for the near UV wavelengths. Experimental results show that the addition of as little as 1% by mass of an additive can significantly reduce the amount of soot present in the engine exhaust, and therefore alter the associated IR radiation from the plume.

**DoD KEY TECHNOLOGY AREA:** Aerospace Propulsion and Power

**KEYWORDS:** Soot Measurement, Kerosene/Oxygen Liquid Rocket Engines, Additive Effects

**MICROELECTROMECHANICAL SYSTEMS FOR SMALL SATELLITE APPLICATIONS**

**Elizabeth Sei Okano-United States Navy**
**B.S., United States Naval Academy, 1994**
**Master of Science in Astronautical Engineering-June 2001**
**Advisors: Rudy Panholzer, Space Systems Academic Group**
**Brij Agrawal, Department of Aeronautics and Astronautics**
**Second Reader: Alfred N. Sorensen, National Reconnaissance Office, Chair Professor**

Microelectromechanical systems (MEMS) have been developing for the past few decades, but recent spaceflight demonstrations have highlighted the potential of this technology as an attractive paradigms shift in how aerospace systems should be developed, maintained and used as the dawn of a new space age emerges. MEMS will generate a revolution in the way people see and control tomorrow's satellites by combining technological advances in sensors, actuators, reactionary systems, spacecraft attitude control systems, information processing and storage with the miniaturization of these components. MEMS will enable the realization of decentralizing satellites and, therefore, create a paradigm shift in the conceptual operation and development process of how people think about using satellites. The vision of what can be achieved from space is no longer bound by what an individual satellite can accomplish, rather, a number of production. This thesis will validate the concepts of MEMS and its applicability to space and conclude by examining possible paths that the Naval Postgraduate School microsatellite, NPSAT1, can take to reducing subsystem power through the use of MEMS components.

**DOD KEY TECHNOLOGY AREAS:** Sensors, Other (Microelectromechanical Systems)

**KEYWORDS:** Microelectromechanical Systems, MEMS, Nanosatellites, Microsatellites, NPSAT1, Gyroscopes

**EXPLOITATION OF NATIONAL SENSORS FOR TERRAIN CATEGORIZATION (U)**

**Charles S. Seitz-Lieutenant Commander, United States Navy**
**B.S., United States Naval Academy, 1982**
**Master of Science in Astronautical Engineering-March 2001**
**Advisors: Richard C. Olsen, Department of Physics**
**Brij N. Agrawal, Department of Aeronautics and Astronautics**

Abstract is classified.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Sensors, Other (Intelligence, Indications and Warning (I&W)

**KEYWORDS:** Sensor Fusion, Multispectral Imaging, Imagery Intelligence, TERCAT

**SIMULATION OF GUIDED AEROASSISTED MANEUVERS FOR PLANETARY MISSIONS**

**Christopher M. Seneko-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1994**
**Master of Science in Astronautical Engineering-December 2000**
**Advisor: I.M. Ross, Department of Aeronautics and Astronautics**
**Second Reader: S.E. Matousek, Jet Propulsion Laboratory**

Aeroassisted maneuvers are distinguished from purely propulsive maneuvers in that aerodynamic forces are used to assist in orbital maneuvers of spacecraft. These types of maneuvers can vary from aerocapture to direct entry. The NASA Solar System Exploration Program lays the foundation for the future of interplanetary exploration using various versions of these aeroassisted maneuvers. The computer program

ACAPS, designed at the Naval Postgraduate School, was developed for the Jet Propulsion Laboratory (JPL) to conduct high-level mission design for exploration missions to Mars. The primary research objective of this thesis was to upgrade the previous version of ACAPS, to produce a tool that provides new capabilities in support of the Solar System Exploration Program. The secondary research objective of this thesis was to provide direct support to JPL mission planners. The first major upgrade was the incorporation of additional planets which allows for simulation at Venus, Saturn, Neptune and Titan. The second focus of work was the incorporation of guidance to include ballute guidance and the Apollo derived Mars Precision Lander guidance algorithm. This thesis also documents how these upgrades were used to support future missions to Venus, Neptune, Saturn and Titan; particularly in the possibilities of using ballutes.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles, Modeling and Simulation

**KEYWORDS:** Aerocapture, Simulation (ACAPS), Aeroassist, National Aeronautics and Space Administration (NASA), Jet Propulsion Laboratory (JPL), Mars Sample Return (MSR) Mission, Mars Micromission, MATLAB, SIMULINK, Ballute, Parachute

## DETONABILITY OF HYDROCARBON/AIR MIXTURES USING COMBUSTION ENHANCING GEOMETRIES FOR PULSE DETONATION ENGINES

**Neil G. Sexton-Lieutenant, United States Navy**
**B.S., United states Naval Academy, 1995**
**Master of Science in Applied Physics-June 2001**
**Advisors: Christopher M. Brophy, Department of Aeronautics and Astronautics**
**James V. Sanders, Department of Physics**
**Second Reader: David W. Netzer, Department of Aeronautics and Astronautics**

This research studied combustion enhancing geometries and shock reflection on generating a hydrocarbon/air detonation wave in a combustion tube. Ethylene was used as a baseline fuel to determine the heavy hydrocarbon fuels such as JP5, JP8, and JP10. Three criteria were used to measure the effectiveness of the combustion enhancing geometries: ability to generate a detonation, wave speed, and time for shock formation. The evaluated geometries included flow-restricting orifice plates and a Schelkin spiral. Detonations occurred when using ethylene in this configuration, but did not develop when using propane. Because propane's overall reaction rate is slower than that of simpler fuels, more larger- and small-scale turbulence to further enhance combustion needs to be generated to create a detonation wave in a short distance when using complex hydrocarbons, such as propane.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power

**KEYWORDS:** Detonation, Pulse Detonation Engine, Deflagration to Detonation Transition, DDT

## COMPUTERIZED BALLISTIC MODELING OF THE COMANCHE TAILFAN SHROUD

**Allen H. Stephan-Captain, United States Army**
**B.S., United States Military Academy, 1991**
**Master of Science in Aeronautical Engineering-December 2000**
**Advisors: E. Roberts Wood, Department of Aeronautics and Astronautics**
**Donald A. Danielson, Department of Mathematics**

The U.S. Army has contracted Boeing-Sikorsky to develop the RAH-66 Comanche, a new, armed reconnaissance helicopter that features stealth technology designed to improve survivability when operating in hostile environments. Ballistic testing is required on the Comanche prior to fielding. Computer based simulations are being employed in order to reduce requirements for expensive live-fire testing. This thesis uses a computer program called Dytran from MacNeal-Schwendler to simulate the effects of an explosive round detonating in the Comanche tailfan shroud. Six test cases involving explosions with varying

amounts of explosive energy, or specific internal energy, are evaluated. From these tests, a curve showing the percentage of structural failure versus the specific internal energy is plotted. Assuming that 20% structural failure of the model equates to a catastrophic failure, this analysis shows that the analyzed section of the Comanche tailfan shroud can withstand an explosion with a specific internal energy of $2.58 * 10^{10}$ $in^2/sec^2$. Any potential threat rounds with specific internal energies greater than $2.58 * 10^{10}$ $in^2/sec^2$ will pose serious threats to the Comanche.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Materials, Processes and Structures, Modeling and Simulation

**KEYWORDS:** Comanche, Ballistic Modeling, Dytrain, Tailfan Shroud

### QUALITY FUNCTIONAL DEPLOYMENT AS A CONCEPTUAL AIRCRAFT DESIGN TOOL

**Rendell K. W. Tan-Major, Republic of Singapore Air Force**
**B.E. (Mechanical), Nanyang Technological University, 1995**
**Master of Science in Aeronautical Engineering-March 2000**
**Advisor: Conrad F. Newberry, Department of Aeronautics and Astronautics**
**Second Reader: Russ W. Duren, Department of Aeronautics and Astronautics**

Quality Functional Deployment (QFD) methodology was applied as a possible system integration tool for use during the conceptual configuration design phase of low speed High Altitude Long Endurance (HALE) UAVs. A four-level QFD model was used to identify important design variables and prioritize those that impact customer attributes. The customer attributes were deployed into performance parameters. The performance parameters were deployed into UAV part characteristics. The part characteristics were deployed into manufacturing processes. The manufacturing processes were deployed into process controls. Based on QFD, the research effort showed that to achieve the customer attributes of high endurance, range, cruise altitude and payload, the important performance parameters are low gross weight, low $C_{D,0}$, high $C_{L,max}$ and a low life cycle cost. The part characteristics considered for the conceptual HALE UAV configuration were maximum utilization of composites, thick airfoil (to increase fuel capacity), high wing fatigue strength and low wing sweep. To achieve the part characteristics, the manufacturing methods considered were autoclaving and filament winding for composites components; milling and precision forging were considered for aluminum alloy components. Manufacturing process controls were also identified. In each QFD matrix, the technical correlations "roof" provided an effective mechanism for comparing each design parameter against other design parameters in order to determine conflicting design requirements.

**DoD KEY TECHNOLOGY AREA:** Other (Aircraft Design)

**KEYWORDS:** Quality Functional Deployment, Aircraft Design, Uninhabited Aerial Vehicle

### REMOTE NANOSATELLITE FORMATION DESIGNS WITH ORBIT PERTURBATION CORRECTION AND ATTITUDE CONTROL/PROPULSION SUBSYSTEM CORRELATION

**Stephen D. Tomlin-Lieutenant, United States Navy**
**B.S., Rensselaer Polytechnic Institute, 1994**
**Master of Science in Astronautical Engineering-June 2001**
**Advisor: Brij N. Agrawal, Department of Aeronautics and Astronautics**
**Second Reader: Alfred N. Sorenson, National Reconnaissance Office Chair Professor**

The innovative idea of distributing the functionality of current larger satellites among smaller, cooperative satellites has been sincerely considered for assorted space missions to accomplish goals that are not possible or very difficult to do with a single satellite. Additionally, the utilization of smaller satellites is

maximized within formations and clusters to conduct missions such as interferometry and earth-sensing. This paper presents a methodology to describe, populate and analyze numerous formation designs employing the use of Hill's equations of motion to describe a formation's dynamics. These equations of motion are then programmed into a MATLAB code to produce Cartesian elements for input into a Satellite Tool Kit™ (STK) simulation that demonstrates numerous possible cluster formation designs. These simulations are then used to determine $\Delta V$ requirements for overcoming LEO-type perturbations that were modeled within STK's High Precision Orbit Propagator (HPOP).

Finally, components from two subsystems [Attitude Determination and Control (ADCS) and Propulsion], using the $\Delta V$ calculations from the simulation analysis and current advances in MicroElectroMechanical systems (MEMS) and nanosatellite technology, are presented based on a mass constraint of 10kg for the entire satellite.

**DOD KEY TECHNOLOGY AREAS:** Aerospace Propulsion, Space Vehicles, Modeling and Simulation

**KEYWORDS:** Satellite Formation, Orbit Dynamics, STK, Nanosatellite, and Satellite Propulsion

### ATTITUDE DETERMINATION OF A THREE-AXIS STABILIZED SPACECRAFT USING STAR SENSORS

**Jay D. Vogt-Lieutenant, United States Navy**
**B.S., University of Colorado, 1991**
**Master of Science in Astronautical Engineering-December 1999**
**Advisors: Harold A. Titus, Department of Electrical and Computer Engineering**
**Brig N. Agrawal, Department of Aeronautics and Astronautics**

The purpose of this thesis is to investigate the application of a six-state discrete Kalman filter for estimates of angular rates based solely on star sensor data. The satellite is in a Molnyia orbit where orbital angular velocity and orbital angular acceleration are predetermined and stored in the on-board computer; such that they will be available each time a star observation is made. A two-axis star sensor will provide two angles to the estimator whereupon the third "unsensed" angle will be predicted; the rates about all three axes are then estimated. The results show that the rate estimates are accurate to within $10^{-7}$ r/s, which is equivalent to the data produced by gyroscopes.

**DoD KEY TECHNOLOGY AREA:** Space Vehicles

**KEYWORDS:** Kalman, Molnyia, MATLAB, Spacecraft, Satellite, Star Sensor, Star Tracker, Estimation, Rate, Gyroscope

### FULL NONLINEAR SIMULATION OF HELICOPTER COUPLED ROTOR-FUSELAGE MOTION USING MATLAB® AND DYNAMIC SIMULATION

**Robert D. Weissenfels-Lieutenant Commander, United States Navy**
**B.S., United States Naval Academy, 1990**
**Master of Science in Aeronautical Engineering-March 2000**
**Advisors: E. Roberts Wood, Department of Aeronautics and Astronautics**
**Robert L. King, Mississippi State University**

This thesis formulates the full nonlinear equations of motion for determining the stability of helicopter coupled rotor-fuselage motion utilizing MATLAB®'s Symbolic Math Toolbox. Using the extended symbolic processor toolbox, the goal of this work was to eliminate the time consuming process of converting Fortran or C code generated by the symbolic processor, MAPLE® into a MATLAB® useable format where it is further incorporated into an 'S-function' to be used in the dynamic simulation environment.

The formulation of the equations of motion utilized in this process is unique in that it uses the complete set of nonlinear terms in the equations of motions without utilizing ordering schemes, small angle assumptions, linearizing techniques, or other simplifying assumptions. After derivation, the equations of motion are numerically integrated using the dynamic simulation software SIMULINK® and a time history plot is generated of blade and fuselage motion. The equations of motion are regenerated with each time step allowing the adjustment of characteristic structural, blade and dampening properties. These time traces can be used to explore the effects of damping nonlinearities, structural nonlinearities, active control, individual blade control, and damper failure on ground resonance.

**DOD KEY TECHNOLOGY AREAS:** Air Vehicles, Computing and Software, Modeling and Simulation

**KEYWORDS:** MATLAB® Symbolic Processor, Helicopter, Ground Resonance, Nonlinear Simulation, Computer Modeling

## A STUDY OF THE FEASIBILITY AND APPLICABILITY OF SHAPE CONTROLLED SPACE BASED INFLATABLE MEMBRANE STRUCTURES

**Craig M. Whittinghill-Lieutenant, United States Navy**
**B.S., United States Naval Academy, 1995**
**Master of Science in Astronautical Engineering-September 2000**
**Master of Science in Space Systems Operations-September 2000**
**Advisors: Brij N. Agrawal, Department of Aeronautics and Astronautics**
**Donald v.Z. Wadsworth, Department of Electrical and Computer Engineering**

Inflatable structures used for space applications offer mass, volume, and cost savings to spacecraft programs, allowing larger space structures to be built. For certain space applications, there are advantages to using large structures. For example, antennas achieve higher gains when they are increased in size. Higher gains equate to higher data throughputs. Therefore, inflatable structures offer improvements in performance to certain types of spacecraft components.

Environmental factors induce surface errors on large inflatable structures. This degrades performance, especially for inflatable antennas. To reduce this degradation, active and passive control systems can be used to sense errors and control the shape of the antenna. One method of applying an active and passive control system is by using piezoelectric films that are either attached to or are part of the inflatable structure.

The result performed for this thesis explored the theoretical performance of a large inflatable space-based antenna via spreadsheet analysis and the physical performance of a piezoelectric film via laboratory experimentation. For the laboratory experiment, the film was attached to a drum and varying internal pressures and voltages were applied. Also, in order to validate the experimental results, an analytical model was created using MSC/PATRAN and MSC/NASTRAN software.

**DOD KEY TECHNOLOGY AREAS:** Space Vehicles

**KEYWORDS:** Piezoelectric Film, Inflatable Structure, Antennas, Communications, Satellite Development

## OPTIMAL PARACHUTE GUIDANCE, NAVIGATION, AND CONTROL FOR THE AFFORDABLE GUIDED AIRDROP SYSTEM (AGAS)

**Timothy Alphonzo Williams-Ensign, United States Navy**
**B.S., United States Naval Academy, 1999**
**Master of Science in Aeronautical Engineering-June 2000**
**Advisor: Isaac I. Kaminer, Department of Aeronautics and Astronautics**
**Second Reader: Oleg A. Yakimenko, National Research Council Research Associate**

This study is a continuation of a previous work concerning the Affordable Guided Airdrop System (AGAS), a parachute system that integrates low-cost guidance and control into fielded cargo air delivery systems. This thesis sought to expand upon the previous study and provide more information and research on this innovative and critical military system. Several objectives and tasks were completed in the course of this research and development. The simulation model used in the previous work for feasibility and analysis studies was moved from a MATLAB/SIMULINK◆ environment to a MATRIX-X◆ environment in anticipation of AGAS future use on an Integrated Systems, Incorporated AC-104 real-time controller. Further simulation and study for this thesis were performed on the new system. The new model implemented characteristics of the G-12 parachute, which eventually will be used in the actual flight testing of the AGAS airdrop. The system of pneumatic muscle actuators (PMSs) built by Vertigo, Incorporated, and used on the AGAS was modeled on the computer also. The characteristics of this system and their effects on AGAS guidance and control were studied in depth. The control concept of following a predicted trajectory based on certain wind predictions and other ideas for control algorithms to minimize fuel gas usage, number of control actuations and final control error were also studied. Conclusions and recommendations for further study were drawn from this project.

**DOD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Other (Parachute, Navigation Guidance and Control)

**KEYWORDS:** MATRIX-X◆ Software, Parachute, Guidance, Navigation, Control, Simulation, Wind Estimation

## ANALYSIS OF TRACKING AND IDENTIFICATION CHARACTERISTICS OF DIVERSE SYSTEMS AND DATA SOURCES FOR SENSOR FUSION

**Dean A. Wilson-Lieutenant Commander, United States Navy**
**B.S.A.E., Virginia Polytechnic and State University, 1990**
**Master of Science in Aeronautical Engineering-June 2001**
**Advisors: Russell Duren, Department of Aeronautics and Astronautics**
**Gary Hutchins, Department of Electrical and Computer Engineering**

In the Command and Control mission, new technologies such as 'sensor fusion' are designed to help reduce operator workload and increase situational awareness. This thesis explored the tracking characteristics of diverse sensors and sources of data and their contributions to a fused tactical picture. The fundamental building blocks of any sensor fusion algorithm are the tracking algorithms associated with each of the sensors on the sensor platform. In support of this study, the MATLAB program *'fusion'* was written to provide acquisition managers a tool for evaluating tracking and sensor fusion algorithm.

The *fusim* program gives the user flexibility in selecting: sensor platforms, up to four sensors associated with that platform, the target types, the problem orientation, and the tracking algorithms to be used with the sensors. The *fusim* program was used to compare tracking algorithms in a multiple sensor/multiple target environment. Specifically, the Probabilistic Data Association Filter, the Interacting Multiple Model Filter, the Kalman Filter and the Constant Gain Kalman Filter were evaluated against multiple maneuvering, non-maneuvering, and fixed targets. It is recommended that this study be continued to evaluate advanced tracking and data association techniques, to expand the program to allow attribute tracking and identification, and to study the Human-Machine Interface aspects of sensor fusion.

**DOD KEY TECHNOLOGY AREAS:** Modeling and Simulation, Sensors, Command Control and Communications, Computing and Software

**KEYWORDS:** Data Fusion, Sensor Fusion, Tracking, Tracking Algorithms, Kalman Filter, Probabilistic Data Association, PDA, Interacting Multiple Models, IMM, Simulation